An Exploratory Study of Variations in Exposure to Environmental Tobacco Smoke in the United States

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There is considerable interest in assessing exposure to environmental tobacco smoke (ETS) and in understanding the factors that affect exposure at various venues. The impact of these complex factors can be researched only if monitoring studies are carefully designed. Prior work by Jenkins *et al.* gathered personal monitor and diary data from 1,564 nonsmokers in 16 metropolitan areas of the United States and compared workplace exposures to ETS with exposures away from work. In this study, these data were probed further to examine (1) the correspondence between work and away-from-work exposure concentrations of ETS; (2) the variability in exposure concentration levels across cities; and (3) the association of ETS exposure concentrations with select socioeconomic, occupation, and lifestyle variables. The results indicate (1) at the population level, there was a positive association between ETS concentrations at the work and away-from-work environments; (2) exposure concentration levels across the 16 cities under consideration were highly variable; and (3) exposure concentration levels were significantly associated with occupation, education, household income, age, and dietary factors. Workplace smoking restrictions were associated with low ETS concentration levels at work as well as away from work. Generally, the same cities that exhibited either lower or higher away-from-work exposure concentration levels also showed lower or higher work exposure concentration levels. The observations suggest that similar avoidance characteristics as well as socioeconomic and other lifestyle factors that affect exposure to ETS may have been in operation in both away-from-work and work settings.

KEY WORDS: ETS; exposure; variability; socioeconomic; lifestyle; regression

1. INTRODUCTION

Various deleterious health effects have been ascribed to environmental tobacco smoke (ETS) exposure; it has been implicated in various respiratory problems[1-3] and in coronary heart disease,[4] as well as in increasing the risk for lung cancer.[5-7] The most difficult issue in the conduct and interpretation of these studies and in the evaluation of potential risk associated with ETS exposure has been the uncertainty in exposure. Understanding the factors affecting ETS exposure leads to improved characterization of the health risk and better design of exposure studies. These factors can be complex. Exposure concentrations can potentially be affected by a wide range of variables that could include physical factors pertaining to the architecture of habitats and workplaces; various

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social, economic, occupational, and lifestyle factors; and seasonal considerations. Further, an individual's exposure to various environmental toxicants might occur in conjunction with poor dietary habits, thereby aggravating the health risks related to the exposure.

Various studies have been conducted both in the United States and elsewhere to evaluate the extent of ETS exposure in different environments.[8–14] Previous studies relied upon the use of area monitors to measure exposure concentrations[13–15] or upon self-reports of exposure incidents to assess exposure indirectly.[16] More recent studies by Jenkins *et al.*[8,9] and Phillips *et al.*[11,12] used personal monitors and included detailed diary and questionnaire data provided by the participants. A large study was conducted by Jenkins *et al.*[8] in 16 U.S. cities using personal monitors on 1,564 nonsmoking participants to measure various gaseous and particulate ETS marker concentrations in work and away-from-work (AFW) environments. That study is perhaps the only extensive one in the United States that enables examination of the relative contribution of an individual's activities and lifestyle factors to ETS exposure. Jenkins *et al.*[8] found that for the majority of individuals who lived or worked in smoking environments, ETS exposure in the AFW environment was greater than the exposure at work due to greater ETS concentration levels in the AFW environment, as well as longer time durations spent away from work. Those authors, however, also found that differences between exposure concentrations in the two environments decreased for the more highly exposed individuals such that exposure concentrations in the workplace were comparable to those incurred AFW.

Salient features of the Jenkins 16-city study are as follows (refer to Jenkins *et al.*[8,9] for further details): Salivary cotinine was measured before and after the study to ensure the subjects were actually nonsmokers. The monitoring took place over the course of 1 day; individuals were selected from a multitude of work environments; and the study was conducted over the course of 13 months. Two separate monitors were used, one for workplace exposures and the other for exposures in environments away from work. The collected monitor samples were analyzed for particulate markers that included respirable particulate matter (RSP); ultraviolet-absorbing particulate matter (UVPM); fluorescing particulate matter (FPM); solanesol and scopoletin; and gaseous markers that included nicotine, 3-ethenyl pyridine (3-EP), and myosmine.

For workplace exposure, the 16-city study generally included only nonmanufacturing workplaces. Among the various exposure scenarios possible away from work, most observations of smoking incidents reported by a participant were in the home environment. The contribution from exposures outside of the home to the overall AFW levels was quite small with the exception of those participants who lived in nonsmoking homes.[8,9] However, a participant wearing a monitor throughout the course of the study could have been influenced to remain at home. Participants completed both screening and additional questionnaire sheets during the study and maintained a detailed diary. The diary and questionnaire data provided valuable information on lifestyle, socioeconomic, and other factors that might pertain to the circumstances of exposure.

Several papers have been published on different aspects of the 16-city study.[8,9,17–19] In a three-part series, LaKind *et al.*[17–19] first considered the impact of demographic variables (income, age, education, race) and workplace types and concluded that these variables did not explain differences in exposure to ETS. (Their analysis is discussed further in the Discussion and Conclusions section.) They next examined the use of ETS constituents as markers for ETS exposure, performing pairwise comparisons of marker concentrations. Finally, the same authors used the marker concentrations obtained in the Jenkins[8] study to derive dose distributions of various ETS-related chemicals in the body.

In this article, we extended the analyses of Jenkins *et al.*[8,9] and LaKind *et al.*[17–19] to probe further into the exposure data gathered by Jenkins *et al.*; the diary and questionnaire information were used in conjunction with the exposure concentration readings from the personal monitors. The primary goal was to examine at an exploratory level the variation in exposure concentration levels, both at the population and at the individual level. We examined whether there was a correspondence between exposure concentrations measured at work and AFW, and if such correspondence existed across the various cities in the Jenkins *et al.*[8] study. Variations in the ETS concentrations to which a population is exposed would be expected to stem from specific underlying variables. Using univariate analyses as well as logistic multiple regression models, several predictor variables were examined including occupation, socioeconomic, and lifestyle factors, which may potentially elucidate the exposure patterns. An additional question was whether these variables affect both work and AFW exposure concentrations qualitatively in the same manner.

2. METHOD

The results presented in this article provide exploratory analyses of the factors underlying ETS concentrations to which individuals are exposed at the AFW and work settings. Various approaches were used. Examined first were scatter plots of ETS marker concentrations at the individual level and the quantiles of these marker concentrations. These quantiles enabled separation of the population into appropriate bins so that various predictor variables could be examined within each of these exposure concentration categories. A logistic multiple regression model was developed to indicate the predictor variables that could best explain the variability in ETS exposure concentrations.

Measured salivary cotinine levels were used to screen out those individuals who may have smoked during the study duration. If cotinine levels greater than 15 ng/mL were detected, the individual was considered to be a smoker and data from that person were not included in the analysis. This provided a study population of 1,498 nonsmoking participants, referred to here as the entire study population. Unless specified otherwise, the analyses in this article are based on data from the entire study population. Some of the analyses were also performed on data from a subset of this population: Those participants who reported observing smoking incidents in their vicinity within the duration of the study. In these cases, individuals who responded "none" to the question "How many cigarettes did you observe being actively smoked near you while you were wearing the monitor?" were excluded. This constraint was created to explore whether the relationship between work and AFW exposure concentrations changed if only subjects who had self-reported exposure to ETS were considered in the study.

Even though data on other marker concentration levels were gathered in the Jenkins *et al.*[8] study, the analysis presented here used only nicotine concentration as an exposure marker. The values were time averaged for the two exposure venues. The effectiveness of various tracers for measuring exposure to the complex gaseous and particulate mixture in ETS has been discussed in the literature.[20,21] Of the various markers, nicotine is easiest to measure, is abundant in sidestream smoke, and has the advantage of being unique to tobacco smoke.[18] The analysis by LaKind *et al.*[18] (of the same data that are used in the present study) found strong linear correlations of nicotine concentrations with UVPM and FPM concentrations. Good linear correlation was found between the exposure concentrations of nicotine and the gaseous markers 3-EP and myosmine.

3. RESULTS

3.1. Marker Concentration Distribution

Examined first was the distribution of nicotine exposure concentration levels. The distribution for the complete data was peaked in the very low exposure concentration regime with a long tail at high concentrations and was far from normal. The log-transformed distribution is shown in Fig. 1. Because marker concentration levels provided in the Jenkins *et al.*[8] data were corrected for levels measured on blank samples on a city-by-city basis, there were a number of values (134) that were reported as zero or negative. These observations were set equal to a very small positive number before they were log transformed. A few extreme outliers were removed from Fig. 1. The transformed distribution is also not normal even if the first bar on the histogram is dropped. Similar behavior was also seen for nicotine concentration levels obtained for exposures at the workplace.

3.2. Correspondence between Exposure Concentrations at Work and Away-from-Work

In Fig. 2A, individual nicotine exposure concentration levels at work are plotted against the concentration levels AFW. Values above the 95th percentile AFW and work exposure concentration levels of the

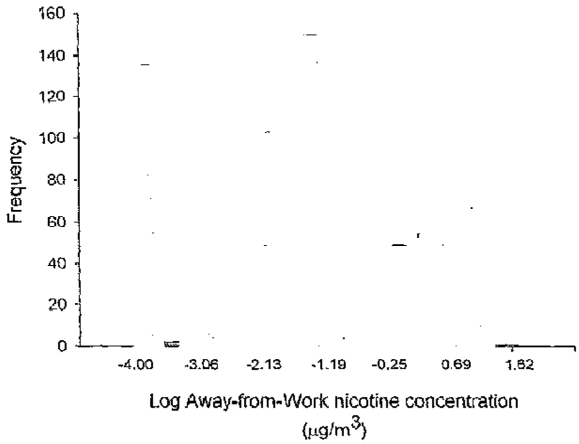

Fig. 1. Distribution of logarithm of nicotine exposure concentrations in the away-from-work venue.

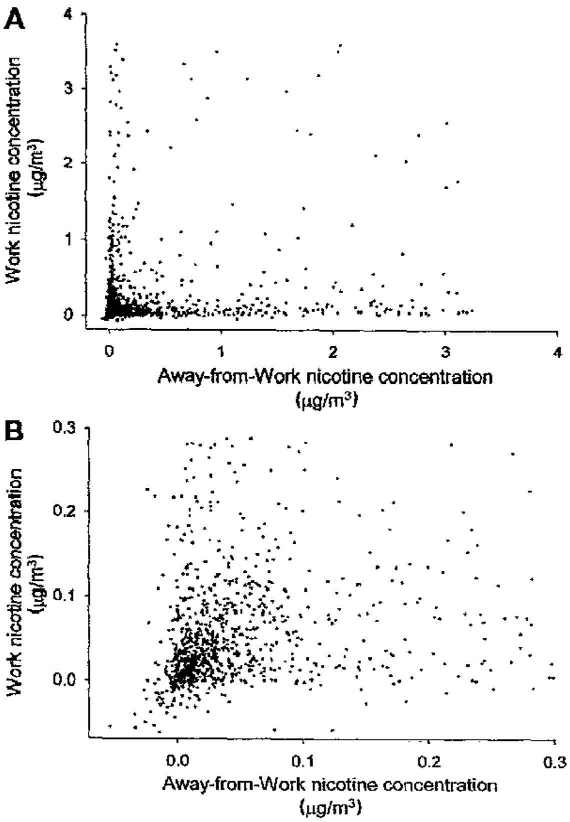

Fig. 2. Scatter plot of individual nicotine exposure concentrations at work versus away-from-work for (A) the entire study population (exposure concentrations greater than the 95th-percentile levels are excluded) and (B) individuals exposed to less than 0.3 $\mu g/m^3$ of nicotine concentration levels both at work and away-from-work.

full population were excluded because inclusion of the complete range made a proper visualization of the data difficult. Most of the data are clustered around extremely low exposure concentrations. In Fig. 2B, the same two variables are shown but only for relatively low concentrations ($<0.3\ \mu g/m^3$ for each). This magnified view also fails to demonstrate any discernible association between the ETS concentrations to which an individual was exposed at work and AFW. This apparent lack of association between individual exposure concentrations remains when the data for each city are plotted separately.

Examined next was whether correspondences were evident at the population level if the exposure concentrations shown in Fig. 1 were appropriately aggregated. The data were binned for this purpose into three intervals based upon the 0 to 60th (bin 1), 60th to 80th (bin 2), and 80th to 100th (bin 3) percentiles of AFW nicotine concentration levels. For the purpose of analyzing associations between exposure concentrations and various predictor variables later in the article, the data were also binned into similar quantile intervals of work concentration levels. Table I gives quantiles of AFW and work nicotine concentration levels, considering first the entire study population of 1,498 individuals and subsequently only 248 individuals who reported observing smoking incidents in the AFW as well as in the work venues. For each population, the differences in the 20th-, 40th-, and 60th-percentile levels are small compared with differences between the 60th-, 80th-, and 100th-percentile levels. Thus each bin represents a sharply defined exposure category. Table I also shows the median concentrations for the three bins for each exposure venue.

Table I. Nicotine Concentration Levels at Quantiles of Away-from-Work and Work Exposure Concentrations

		Away-from-work concentrations ($\mu g/m^3$)		Work concentrations ($\mu g/m^3$)	
Bin	Percentiles	All subjects (N = 1,498)	Subjects reporting incidents (n = 248)	All subjects (N = 1,498)	Subjects reporting incidents (n = 248)
	0	−0.054	−0.018	−0.079	−0.034
	20	0.009	0.067	0.011	0.063
1 (0%–60%)	40	0.028 [0.016]	0.278 [0.143]	0.036 [0.022]	0.182 [0.103]
	60	0.069	0.965	0.082	0.660
2 (60%–80%)	80	0.421 [0.143]	2.81 [1.64]	0.279 [0.129]	3.17 [1.36]
3 (80%–100%)	100	162.0 [1.70]	162.0 [5.07]	334.0[a] [1.11]	37.9 [5.99]

Note: Values in brackets are bin medians.
[a] This unusually high reading is possibly spurious as it corresponds to an individual who did not observe any tobacco products smoked in his vicinity and whose work setting allowed smoking only in designated areas. For this subject, the away-from-work exposure concentration was within the 40th-percentile level.

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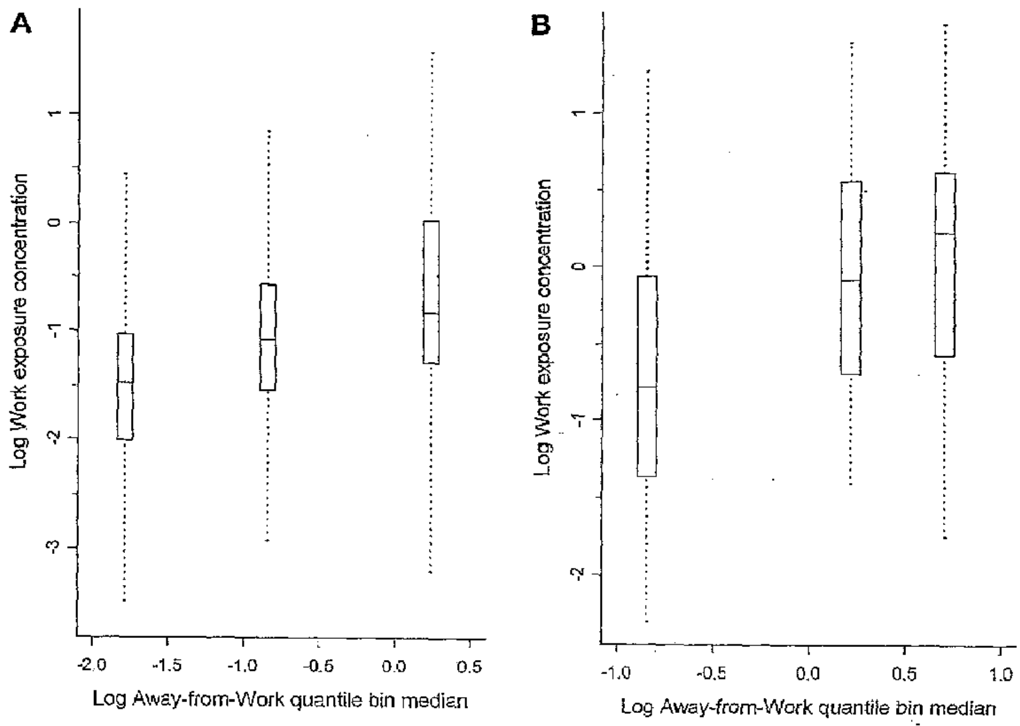

Fig. 3. Box-whisker plots of log nicotine exposure concentration levels at work for (A) the entire study population and (B) the population of individuals who reported observing one or more incidents of smoking both at work and away-from-work (AFW) plotted at the median log AFW nicotine exposure concentration levels for each AFW quantile bin. Outliers are not shown. The boundaries of the bins are at the 0%, 60%, 80%, and 100% levels of AFW nicotine concentrations.

In order to examine a correspondence between exposure concentration levels in the AFW and work venues, the bins were considered based upon the AFW quantile intervals. The log-transformed work concentration levels of individuals in each bin were then analyzed. Box-whisker plots (without outliers) of the logarithm of work concentrations for each AFW quantile bin were then plotted at the logarithm of the median AFW concentration level (x axis) for each bin. Outliers in this analysis are data points that fall outside of the whisker extremes. The maximum extents of the whiskers beyond each end of the box are given by 1.5 times the interquartile range as measured from either end of the box. A bar within the box denotes the median work exposure concentration for that bin. These plots are shown in Fig. 3A for the entire study population. In Fig. 3B, a similar plot is shown for the restricted data of 248 participants who indicated in their questionnaires that they observed one or more cigarettes being smoked in both the AFW and work environments.

In Fig. 3A and 3B, the boxes (interquartiles) and medians for the log work exposure concentration levels increase with quantiles of log AFW concentration levels, supporting the conclusion that at the population level exposure concentrations of ETS at work were associated with those in the AFW setting. In Fig. 3B, the work and AFW medians and interquartiles in each bin are shifted significantly higher from the corresponding levels in Fig. 3A. Such a shift must be expected because data from individuals who did not observe incidents of smoking in both venues[2] and those comprising 45% of the overall study population were removed from the analysis due to the restriction imposed on this category of data points. The results in Fig. 3 raise the possibility that the primary variables associated with the ETS concentration levels to

[2] Specifying such individuals as being unexposed is problematic, for it relies on the individual's awareness of incidents in the environment; nevertheless, such a criterion is freely used in various studies on ETS exposure assessment.

which a population is exposed could be similar in the AFW and work environments. Associations between different variables and ETS exposure concentrations are explored in the remainder of this article.

The spread in the log work concentration levels in each bin is given by the box limits and the whiskers. The extent of the whiskers for the work exposure data in any bin in Figs. 3A and 3B envelopes the boxes in the other two bins. The large spread detailed by the whiskers illustrates why the association observed earlier between work and AFW exposures of a population was not apparent from the scatter plots of Fig. 2. Although not shown here, a similar pattern was observed when the data are binned according to quantiles of work exposure concentration levels. In either case, the large spread in the exposure concentrations along the ordinate of the lowest bin indicates that a significant number of individuals who are ex-

Table II. Association of Environmental Tobacco Smoke Exposure Concentration with Education

	% with higher education[b]		% with high school education or less[c]	
Exposure bin[a]	AFW exposure	Work exposure	AFW exposure	Work exposure
1 (0%–60%)	45.0 (404/898)	41.3 (368/890)	54.9 (493/898)	58.5 (521/890)
2 (60%–80%)	30.1 (90/299)	35.5 (105/296)	69.9 (209/299)	64.5 (191/296)
3 (80%–100%)	19.4 (58/299)	24.2 (72/297)	80.6 (241/299)	75.8 (225/297)
p value	<0.001	<0.001	<0.001	<0.005

[a] Boundaries of bins are at the 0%, 60%, 80%, and 100% nicotine AFW and work exposure concentration levels.
[b] Number of individuals with completed college or graduate education expressed as a percentage of the total number in each bin (actual numbers are given in parentheses).
[c] Number of individuals with some/completed high school education expressed as a percentage of the total number in each bin (actual numbers are given in parentheses).

Table III. Association of Environmental Tobacco Smoke Exposure Concentration with Household Income

	% with household income ≥$75,000[b]		% with household income $30,000–$75,000[b]		% with household income ≤$30,000[b]	
Exposure bin[a]	AFW exposure	Work exposure	AFW exposure	Work exposure	AFW exposure	Work exposure
1 (0%–60%)	11.9 (107/898)	11.9 (106/890)	63.8 (573/898)	61.5 (547/890)	23.2 (208/898)	25.7 (229/890)
2 (60%–80%)	6.4 (19/299)	7.4 (22/296)	50.8 (152/299)	57.1 (169/296)	42.1 (126/299)	34.8 (103/296)
3 (80%–100%)	5.7 (17/299)	5.1 (15/297)	55.5 (166/299)	56.2 (167/297)	38.5 (115/299)	38.0 (113/297)
p value	0.001	0.002	0.02	0.49	<0.001	<0.001

[a] Boundaries of bins are at the 0%, 60%, 80%, and 100% AFW and work nicotine exposure concentration levels.
[b] Numbers of individuals with annual household income in this range expressed as a percentage of the total number in each bin (actual numbers are given in parentheses).

Table IV. Association of Environmental Tobacco Smoke Exposure with Diet

	% on Diet A[b]		% on Diet B[c]	
Exposure bin[a]	AFW exposure	Work exposure	AFW exposure	Work exposure
1 (0%–60%)	14.7 (132/898)	13.8 (123/890)	37.3 (335/898)	37.6 (335/890)
2 (60%–80%)	19.4 (58/299)	18.9 (56/296)	34.4 (103/299)	29.1 (86/296)
3 (80%–100%)	21.7 (65/299)	24.6 (73/297)	25.1 (75/299)	30.3 (90/297)
p value	0.021	<0.001	0.007	0.036

[a] Boundaries of bins are at the 0%, 60%, 80%, and 100% AFW and work nicotine exposure concentration levels.
[b] Number of individuals eating red meat, pork, or eggs once or more every day expressed as a percentage of the total number in each bin (actual numbers are given in parentheses).
[c] Number of individuals eating red meat, pork, or eggs once a week or less expressed as a percentage of the total number in each bin (actual numbers are given in parentheses).

Table V. Association of Environmental Tobacco Smoke Exposure Concentration with Age

Exposure bin[a]	% between 18 and 25 years old[b]		% between 26 and 50 years old[c]		% over 50 years old[d]	
	AFW exposure	Work exposure	AFW exposure	Work exposure	AFW exposure	Work exposure
1 (0%–60%)	9.4 (84/898)	9.8 (87/890)	75.4 (677/898)	76.0 (676/890)	15.3 (137/898)	14.3 (127/890)
2 (60%–80%)	17.4 (52/299)	15.9 (47/296)	67.9 (203/299)	69.6 (206/296)	14.7 (44/299)	14.5 (43/296)
3 (80%–100%)	16.4 (49/299)	17.5 (52/297)	68.9 (206/299)	64.3 (191/297)	14.7 (44/299)	18.2 (54/297)
p value	<0.001	0.001	0.29	0.10	1.00	0.30

[a] Boundaries of bins are at the 0%, 60%, 80%, and 100% AFW and work nicotine exposure concentration levels.
[b] Number of individuals in the 18–25 age group expressed as a percentage of the total number in each bin (actual numbers are given in parentheses).
[c] Number of individuals in the 26–50 age group expressed as a percentage of the total number in each bin (actual numbers are given in parentheses).
[d] Number of individuals in the over-50 age group expressed as a percentage of the total number in each bin (actual numbers are given in parentheses).

posed to very low concentrations of ETS in one exposure venue were exposed to much higher concentrations of ETS at the other venue.

Examined next was the association of ETS exposure concentrations at AFW and work environments with select socioeconomic, occupation, and lifestyle variables. Tables II through V and Fig. 4 compare the frequency of individuals in different categories of education, household income, dietary patterns, age, and occupation, respectively, binned into the three nicotine exposure concentration quantile intervals for AFW and work exposures. The frequency is expressed as a percentage of the total number of individuals in a particular quantile bin with the actual numbers shown in parentheses or on top of the bars. It must be noted that the bins used for the AFW and work environments were partitioned differently based upon quantiles of exposure concentrations at each exposure venue. Of the 1,498 study participants, there were some for whom AFW or work nicotine concentrations were not reported in the database. This reduced the number of nicotine exposure concentrations available for the overall analysis to 1,496 for the AFW exposure, and to 1,483 for the work exposure. In general, in Tables II, III, and Fig. 4 the numerators in each subcategory of the explanatory variable do not add up to the denominator for a specific bin and exposure venue. This is because some of the subjects did not mark a response for any specific subcategory in their questionnaire or diary sheets, whereas exposure concentrations were reported for such individuals.

The differences between the number of individuals in each bin for the various categories examined were tested for statistical significance using a chi-square test, the null hypothesis being that the number

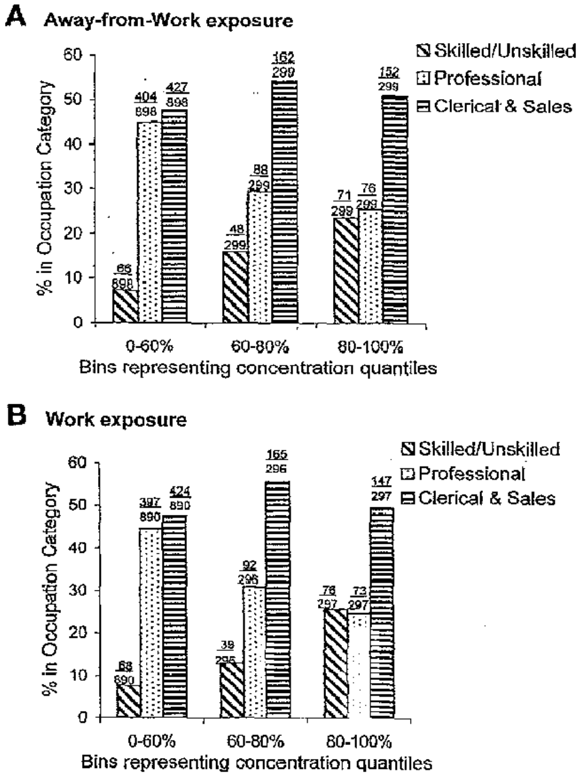

Fig. 4. Association of environmental tobacco smoke exposure with selected occupation categories. Histograms of individuals in selected occupation categories were binned into quantiles of exposure concentration levels. The frequency is expressed as a percentage of the total number of individuals in a particular quantile bin. The boundaries of the three bins are at the 0%, 60%, 80%, and 100% levels of nicotine exposure concentrations; (A) binning was based upon away-from-work exposure concentrations; (B) binning was based upon work exposure concentrations.

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of individuals in each case are not different from that expected from a uniform distribution of individuals among the quantile bins.

3.3. Associations of Exposure Concentration with Education, Household Income, and Occupation

Table II shows the distribution of individuals grouped into two education levels in the exposure concentration bins for AFW and work exposures. Individuals with completed college or graduate education were compared with individuals who did not pursue completed education beyond high school (this includes individuals who did not complete high school or those who dropped out of college). For each education level, individuals were binned into quantiles of AFW and work nicotine concentration levels. The table shows that the proportion of individuals in the higher education group is highest below the 60th-percentile level of exposure concentration, and decreases with increasing exposure category. On the other hand, the pattern is reversed for the group with lower education level; the proportion of individuals with lower education is least in the lowest exposure bin. Although the trend is similar, the differences between the frequencies for exposure at work are not as significant as that for exposure AFW.

Table III shows the distribution of individuals grouped into three annual household income categories—$75,000 or more, between $30,000 and $75,000, and less than $30,000—binned into the three exposure concentration categories for the two exposure venues. For each income level, individuals were binned into quantiles of AFW and work nicotine concentration levels. Individuals in the higher household income group were largely concentrated in the lowest exposure quantile bin with the frequency decreasing with increasing exposure concentration. The group with household incomes between $30,000 and $75,000 had a higher proportion of individuals in the lowest quantile bin for AFW, whereas no significant differences between the proportions of individuals were observed for exposure at work. For the lower household income group, the lowest exposure quantile bin had the smallest proportion of individuals for both exposure venues. Jenkins *et al.*[9] also examined the 24-hr median exposure concentrations time averaged over work and AFW venues and found exposure concentrations to be generally inversely related to household income.

It was difficult to separate individuals into categories of job titles because of the wide range of jobs and also because the number of individuals in certain positions was much larger than those in others. Therefore, individuals were separated into broad occupation categories to analyze the association of ETS exposure concentrations with occupation. Individuals in the skilled, semiskilled, unskilled, and service workforce were lumped together into a skilled/unskilled category; those belonging to professional/semiprofessional and managerial occupations were grouped into a category denoted as professional; and all those in clerical, sales, and office categories of work were included in the clerical/sales category. Other occupations were not included because their numbers were low. Figure 4 provides the number of individuals in a specific occupation category in a given quantile bin as a percentage of the total number of individuals in that bin. Figures 4A and 4B show AFW exposures and work exposures, respectively. The histograms for both exposure venues show that individuals in the skilled/unskilled workforce were largely distributed in the higher exposure concentration bins with the percentage in Bin 3 greater than that in Bin 1 by roughly a factor of three. This is to be contrasted with individuals in the professional category, for which the proportion of individuals was less for Bin 3 than for Bin 1 by roughly a factor of two. On the other hand, individuals in the clerical/sales category appear to be uniformly distributed across the various exposure concentration bins in both venues.

3.4. Association of Exposure Concentration with Diet

Table IV shows the associations of ETS exposure concentration in each exposure venue with some diet categories. The questionnaire sheets collected in the study provided the frequency of consumption of various food items. Individuals were asked to "indicate how frequently you consumed the following food items on an average over the course of the previous month." Individuals in the category marked Diet A consumed red meat, pork, or eggs once or more every day (signifying a high-fat diet); those in the Diet B category consumed those food items only once a week or less (signifying a low-fat diet). We make these distinctions with the caveat that they are exploratory attempts to pool individuals into different dietary extremes and that no attempt was made to examine if specific thresholds for levels of fat were exceeded. Table IV indicates that the population of individuals on Diet A were prone to be exposed to higher concentrations of ETS both AFW and at work, whereas in general, the opposite effect was seen for the population on Diet B.

3.5. Association of Exposure Concentration with Age

Table V presents the association of ETS exposure concentrations AFW and at work for the two extreme age groups in the study population—the 18-to-25-years and the 50+-years age groups—and a third group consisting of the rest. The lower age group evidenced a trend toward higher exposure concentrations in both exposure venues, whereas the other age groups showed no statistically significant relationship with exposure.

3.6. Variation of ETS Exposure Concentrations across 16 Cities

In the Jenkins *et al.*[8] data, the 1,564 individuals in the study were distributed uniformly across the 16 cities, allowing an examination of variations across cities in exposure concentration levels, as well as how these variations compare between the AFW and work settings. The cities in the study are listed in Table VI. In Fig. 5, box and Whisker plots of the logarithm of nicotine concentration levels are shown for the 16 cities; Fig. 5A shows the AFW exposures and Fig. 5B the work exposures. The figures indicate large intercity and intracity variations in exposure concentrations for both settings. A Kruskal–Wallis analysis of variance on ranks was performed to confirm the hypothesis that the differences in the median values of the marker levels across the 16 cities for the AFW and work environments were statistically significant ($p <$ value 0.001). For both exposure venues, the range in median concentrations was roughly an order of magnitude, and

Table VI. City Codes Used in the Study

1	Knoxville, TN
2	Portland, ME
3	San Antonio, TX
4	Fresno, CA
5	Boise, ID
6	Seattle, WA
7	Baltimore, MD
8	Columbus, OH
9	Daytona Beach, FL
10	Buffalo, NY
11	St. Louis, MO
12	Grand Rapids, MI
13	Camden/Philadelphia, NJ/PA
14	Indianapolis, IN
15	Phoenix, AZ
16	New Orleans, LA

Note: Based on Jenkins *et al.*[8]

the upper quartiles of some cities were comparable to the lower quartiles of many other cities.

The cities analysis is continued in Fig. 6 in which the median work and AFW nicotine concentration levels for each city are plotted against each other—shown in Fig. 6A for the entire study population and in Fig. 6B for the restricted data only from individuals who reported observing smoking incidents in their vicinity at the exposure venue under consideration. A line of regression drawn through these points reveals an R^2 of 0.60 in both cases. The city codes are marked alongside each point. In Fig. 6B, the data strongly support a linear relationship, $R^2 = 0.96$, between median work and AFW exposure concentration levels if Cities 9 and 16 (Daytona Beach and New Orleans) are excluded, raising the possibility that within each of the remaining 14 cities, factors that determine exposure concentration levels may generally play similar roles in either exposure venue. Why the exposure in cities 9 and 16 are exceptions to this pattern could not be determined.

3.7. Logistic Multiple Regression Models

Logistic multiple regression methods[22] were also applied to identify the key predictors of variability in exposure concentrations by characterizing a high or low exposure—values of 1 or 0, respectively for the outcome variable—based upon whether the work or AFW exposure concentration for an individual was at/above or below the 80% level, respectively. This was then regressed against the individual's status (coded as 1 or 0) for a host of independent variables, shown in Table VII for exposure AFW and in Table VIII for exposure at work. The odds ratio (OR) relating a particular predictor variable to the exposure concentration was calculated relative to individuals in chosen reference groups after controlling for all other variables. The reference was comprised of the following subcategories: gender—male, marital status—unmarried, age—36 to 50 years, occupation—clerical/sales, education—completed college or graduate school, household income—$41,000 to $50,000, diet—diet categories not specified under Diet A or Diet B, work smoking restrictions—total ban on smoking.

Table VII indicates that occupation, education, household income, restrictions on smoking at work, and diet were significant predictors of ETS concentration levels to which an individual is exposed at the AFW venue. The odds in favor of high exposure concentrations for individuals in the skilled/unskilled workforce in relation to individuals in the clerical/sales

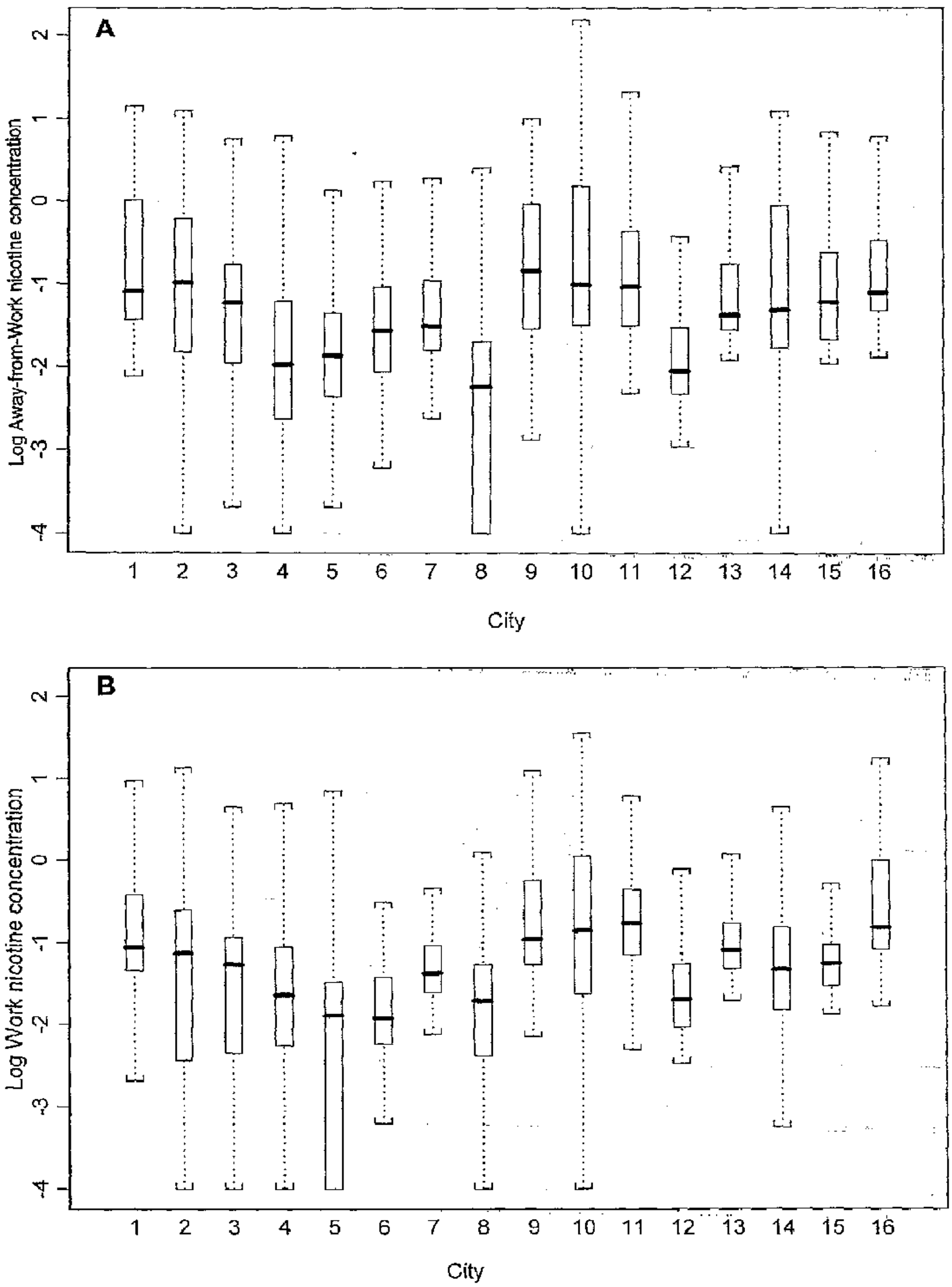

Fig. 5. Intercity and intracity variations in environmental tobacco smoke exposure for (A) away-from-work exposure and (B) work exposure. Box-whisker plots of log nicotine concentration levels are for the 16 cities in the study. City codes are given in Table VI.

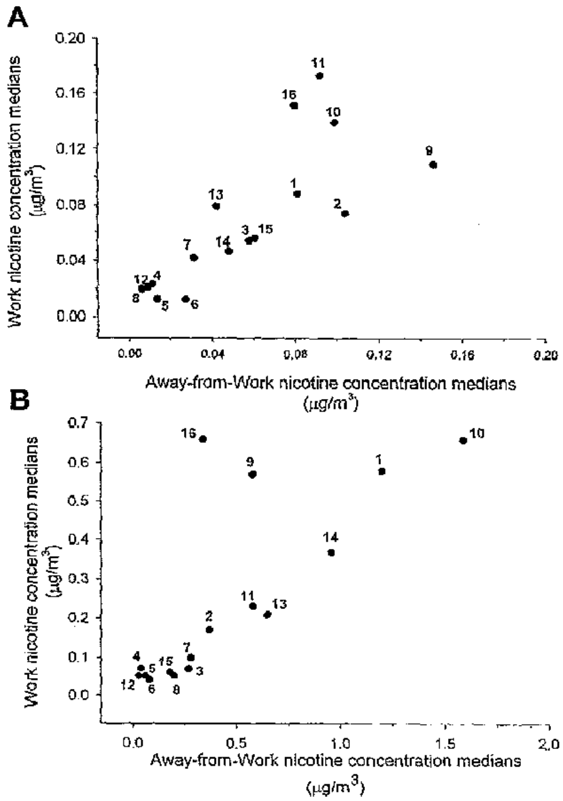

Fig. 6. Association between work and away-from-work (AFW) median exposure concentrations across cities. Median nicotine concentration levels for exposure at work versus median levels for exposure AFW are plotted for each city. City codes are given in Table VI. In (A) the entire study population was used in the analysis. In (B) only those individuals who reported observing incidents of smoking at each environment were included in the analysis for that environment. (Note: This restriction is different from that used in Fig. 2A in which individuals who reported observing incidents at both exposure venues were included.)

Table VII. Logistic Multiple Regression Models of Away-from-Work Nicotine Exposure Concentration

Independent variable	OR	CI
Intercept	0.31	(0.19, 0.51)
Gender		
Female	1.22	(0.93, 1.58)
Male[a]	1.00	
Marital status		
Married	0.86	(0.66, 1.13)
Unmarried[a]	1.00	
Age		
18–25 years	1.28	(0.88, 1.87)
26–35 years	0.92	(0.71, 1.20)
36–50 years[a]	1.00	
>50 years	0.85	(0.61, 1.19)
Occupation[b]		
Skilled/unskilled	2.25	(1.58, 3.21)
Professional	0.94	(0.70, 1.25)
Clerical/sales[a]	1.00	
Education		
High school or less	1.81	(1.38, 2.38)
College/grad school[a]	1.00	
Household income		
>$75,000	0.94	(0.58, 1.52)
$50,000–$75,000	1.08	(0.76, 1.55)
$40,000–$50,000[a]	1.00	
$30,000–$40,000	1.21	(0.84, 1.73)
$20,000–$30,000	1.69	(1.15, 2.50)
<$20,000	1.78	(1.17, 2.71)
Work smoking restrictions		
No restrictions	1.94	(1.37, 2.73)
Smoking in designated areas	1.24	(0.97, 1.59)
Total ban[a]	1.00	
Diet[c]		
Diet A	1.06	(0.78, 1.45)
Diet B	0.71	(0.55, 0.92)
Diet C[a]	1.00	

Note: OR = adjusted odds ratio; CI = 95% confidence interval.
[a] Group with reference to which the OR was calculated.
[b] The subcategories have been abbreviated. See text for complete listing.
[c] Diet A: Red meat, pork, or eggs once or more every day; Diet B: red meat, pork, or eggs once a week or less; Diet C: categories not specified under Diets A or B.

category were greater by a factor of 2.3; those of individuals without college or higher education were greater by a factor of 1.8; and those of individuals whose annual household income was less than $30,000 were greater in relation to those in the category of $41,000 to $50,000 by a factor of 1.7 to 1.8. Of interest is that individuals whose workplaces had no restrictions on smoking were nearly twice as likely to be exposed to higher concentrations of ETS away from work as those whose workplaces had a total ban on smoking. The odds in favor of high exposure concentrations for individuals on diets that were likely to be low in fat (Diet B) were only 0.7 times the odds of those on diets that were considered neither high nor low in fat (Diet C). The ORs for the age groups show a decreasing trend with age but the results were not statistically significant.

The most (and highly) significant predictor of ETS concentration levels to which an individual was exposed at work was the variable indicating workplace smoking restriction status (Table VIII). Age and occupation were also significant predictors of exposure concentration levels at work. The odds in favor of high exposure concentration levels for the youngest

Table VIII. Logistic Multiple Regression Models of Work Nicotine Exposure Concentration

Independent variable	OR	CI
Intercept	0.27	(0.16, 0.47)
Gender		
Female	0.27	(0.68, 1.20)
Male[a]	1.00	
Marital status		
Married	1.20	(0.89, 1.61)
Unmarried[a]	1.00	
Age		
18–25 years	1.85	(1.23, 2.78)
26–35 years	1.10	(0.82, 1.47)
36–50 years[a]	1.00	
>50 years	1.15	(0.80, 1.66)
Occupation[b]		
Skilled/unskilled	1.80	(1.24, 2.63)
Professional	0.68	(0.50, 0.92)
Clerical/sales[a]	1.00	
Education		
High school or less	0.94	(0.70, 1.26)
College/grad school[a]	1.00	
Household income		
>$75,000	0.79	(0.48, 1.32)
$50,000–$75,000	0.97	(0.66, 1.42)
$40,000–$50,000[a]	1.00	
$30,000–$40,000	1.05	(0.71, 1.55)
$20,000–$30,000	1.32	(0.86, 2.01)
<$20,000	1.56	(0.99, 2.46)
Work smoking restrictions		
No restrictions	15.50	(10.16, 23.66)
Smoking in designated areas	3.64	(2.83, 4.69)
Total ban[a]	1.00	
Diet[c]		
Diet A	1.23	(0.88, 1.71)
Diet B	0.77	(0.58, 1.00)
Diet C[a]	1.00	

Note: OR = adjusted odds ratio; CI = 95% confidence interval.
[a] Group with reference to which the OR was calculated.
[b] The subcategories have been abbreviated. See text for complete listing.
[c] Diet A: red meat, pork, or eggs once or more every day; Diet B: red meat, pork, or eggs once a week or less; Diet C: categories not specified under Diets A or B.

age group (18–25 years) were about twice those of the middle-age group (36–50 years). Relative to individuals in the clerical/sales category, the OR for individuals in the skilled/unskilled workforce was 1.8, whereas that of professionals was only 0.7. Household income was a weak predictor of workplace exposure concentration. Although the OR of individuals whose household income was less than $20,000 was 1.6 in relation to the $41,000-to-$50,000 category, it was only marginally significant. The odds in favor of high exposure concentrations at work for individuals on diets that were likely to be low in fat (Diet B) were only 0.8 times the odds of those on diets that were considered neither high nor low in fat (Diet C), but this result was also only marginally significant.

4. DISCUSSION AND CONCLUSIONS

The distribution of nicotine concentration levels to which nonsmokers are exposed at the work and AFW environments was seen to be highly skewed. The log normally transformed values were also not normally distributed. The exposure concentrations for the bulk of the population were at values that are several orders of magnitude lower than those at higher quantiles of exposure concentration, even when only those individuals who reported observing incidents of smoking were considered in the analysis.

Plots of work versus AFW exposure concentrations of individuals appear extremely scattered. Features emerge, however, when the data are appropriately aggregated by creating exposure categories based upon quantiles of AFW exposure concentrations. Median and interquartiles of exposure concentrations at work determined within each of these exposure categories increase with quantiles of AFW exposure concentrations. Such a correspondence suggests the hypothesis that factors influencing ETS concentration levels to which a population is exposed could be similar in the two exposure environments.

ETS exposure concentrations appear to be associated with education, household income, and occupation, and these associations are prevalent regardless of the exposure environment. In general, the variables considered in the analyses are likely to be interrelated. The more educated and the more affluent segments of the population appear generally more likely to be exposed to lower concentrations of ETS than those with much lower levels of education and household income. Professionals, semiprofessionals, and managers are prone to exposures of lower ETS concentrations, whereas the category consisting of workers in the skilled/unskilled/service sector is likely to be exposed on the whole to higher levels of ETS. These associations point to both social and economic class considerations as determinants of exposure to ETS. Associations along these lines have also been made by others. Curtin, Morabia, and Bernstein[23] observed that women from lower socioeconomic classes had more intense and longer ETS exposures than women from higher socioeconomic classes. Using the prevalence of cigarette smoking as a criterion of exposure, King, Strouse, Hovey, and Zehe[24] reported that ETS

exposure in the home was inversely related to age and education, and that workers in crafts, trades, and general labor occupations had a significantly higher probability of exposure to ETS at work.

The 18-to-25-years age group was associated with higher exposure concentrations of ETS. Dietary extremes also showed interesting associations with exposure concentration levels. The group likely to have higher levels of fat in their diet was associated with higher levels of ETS exposure concentration compared with the group on diets considered to be low in fat. The correspondence between ETS exposure and dietary patterns has been of interest to epidemiologists for various reasons. Exposure to ETS has been reported to be associated with a risk of lung cancer in various studies,[6,7] and for smokers it has been shown that diet may influence the risk of lung and other cancers.[25,26] Matanoski, Kanchanaraksa, Lantry, and Chang[27] found that nonsmoking women not exposed to ETS took much higher amounts of vitamins and vitamin supplements and consumed less alcohol than exposed, nonsmoking women. Other studies[28-30] have also indicated that nonsmoking individuals exposed to smokers have different dietary patterns than those who are not exposed.

These associations, based upon univariate observations on quantile groupings, are largely in agreement with the results of logistic multiple regression analyses. The logistic regression points to several similar factors as significant predictors of ETS concentration levels to which an individual is exposed at work and AFW. It indicates that the variables for occupation, education, household income, diet, and workplace smoking restrictions considered in the models are significant predictors of exposure concentrations AFW, and that workplace smoking restrictions, occupation, and age are significant predictors of exposure concentrations at work. In contrast to these conclusions, LaKind *et al.*[17] concluded that income, age, workplace types, and education did not explain differences in exposure to ETS. Their univariate analysis of the Jenkins *et al.* data[8] was based upon self-reports of the smoking or nonsmoking status of an individual's work or AFW environment from responses obtained in an initial telephone interview prior to the study. LaKind *et al.*[17] then examined distributions of the various sociodemographic attributes of this population. It therefore appears that such an approach is a poor surrogate for using the personal exposure data contained in the Jenkins *et al.*[8] study.

Although the imposition of smoking restrictions at work was associated with lower exposure concentrations at work, as is to be expected, it was also associated with lower concentrations to which nonsmokers are exposed AFW. Farkas, Gilpin, Distefan, and Pierce[31] reported a somewhat analogous cross-venue effect in smokers. They found that workplace smoking restrictions were positively associated with higher rates of cessation attempts and higher rates of light smoking in daily smokers.

Large intercity and intracity variations were seen in ETS exposure concentrations. Regression of median work exposure concentration levels against median AFW exposure concentration levels for each city supports a linear relationship, suggesting that within each city factors that affect exposures may play a similar role in either exposure venue. City as a variable may be a surrogate for other explanatory variables, such as seasonal, geographical, or lifestyle factors. Clearly, to identify the reasons for the observed variability in exposure across cities these variables need to be incorporated in the regression analysis in an appropriate manner.

The results of this research indicate that exposure to ETS is likely to be conditioned by socioeconomic, occupational, and lifestyle factors, and point to reasons as to why avoidance to ETS exposure may operate at similar levels at home and at work. Thus, factors influencing ETS exposure patterns are complex and need to be taken into account in assessing exposure to ETS.

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